Table of Contents

ABSTRACT

Original Project Goals:

- Identify wetlands with remote sensing.
- Develop a matrix to compare results and techniques.
- Produce a user-friendly "cook-book" to guide application of remote sensing technology to wetland projects.

We found that wetlands can be identified visually with panchromatic and multi-spectral images and by computer when using multi-spectral images. Low resolution, 30 meter, satellite images are appropriate for examining regions, township or larger areas. Higher resolution images, 1 to 5 meters, are appropriate for areas of several square miles or less.

Within a few decades increased demand should drive down acquisition costs and the desire to have the information will make image attainment and interpretation common place among natural resource agencies. Satellite image-use, while now specialized, should become as common place as the geographic information systems, Internet usage, and e-mail in the 1990s.

ACKNOWLEDGEMENTS

The Wetland Image Analysis project is funded jointly by the U.S. Environmental Protection Agency and the Missouri Department of Natural Resources. The Water Resources Program of the Missouri Department of Natural Resources' Geological Survey and Resource Assessment Division manages the grant and has contracted with Missouri Resource Assessment Partnership for remote sensing and image processing consultation.

Agencies listed below are providing assistance and consultation during project development:

Missouri Department of Conservation
National Resources Conservation Service
University of Missouri - Columbia
US Army Corps of Engineers
US Fish and Wildlife Service

Robert Clark and Bill Winston were the principle staff that initiated this grant. Clayton Blodgett with the assistance of Melissa Bates provided expert image processing supervision. Blodgett was crucial to the technical methods in developing the images. Raju Kakarlapudi of EPA Region IIV and Steve A. McIntosh of GSRAD in Natural Resources provided administrative assistance and project oversight. McIntosh and Blodgett completed the project and final products.

INTRODUCTION

The Missouri Department of Natural Resources is in need of a method to inventory and access the status of Missouri's wetlands. Most Missouri wetlands have been converted by removing the wetland soils, plant and hydrology. Converted wetlands have lost one or more of their original functions. Grading, filling, paving, drainage, and water diversion are the most common types of conversions. These are the three characteristics that define a wetland as a transitional area between uplands and water bodies. By removing frequent flooding through de-watering, and by covering the hydric soils with fill, wetland vegetation is destroyed and the formerly wet soils become available for development of residential areas, farmland or other floodplain uses. Many small wetland areas have also been inundated by reservoirs creating open water habitats in place of the transitional wetlands. Wetlands are also disappearing naturally and not being replaced. The natural filling of oxbow lakes of the Missouri River floodplain by sediment deposition has been occurring and re-occurring since the ice ages and before. The difference in modern times is that the wetland replacement process has been attenuated. Man-made stream channel straightening, channel stabilization, bank armoring, floodplain levees and drainage-ways now keep new wetlands from forming where historically they would have been recreated.

With the advent of computerized geographic information systems and their recent user friendly adaptations and the National Wetlands Inventory source data, a baseline is being developed for total wetland acreage. The Missouri Department of Conservation has made progress in creating user-friendly access databases and may continue this work. Still, it is very difficult to track changes in the widely dispersed remaining wetlands and some of the databases, such as the one used by the United States Department of Agriculture, remains semi-closed to the public. Computerized GIS data files from the regulatory agencies responsible for wetland regulation, the U.S. Army Corps of Engineers, and the Natural Resources Conservation Service branch of the USDA, are currently not being collected and are not available to the states and the public.

A user-friendly scanning technique to detect land-use changes could be used to determine remotely-spaced wetland changes. This project is to determine the utility of current satellite images that can be purchased and processed (developed) in determining wetland presence, absence, and types.

WETLAND SITES

Lisbon Bottoms, Howard County, June 21, 2001

Lisbon Bottoms is a newly acquired federal refuge area that has a nearly identical sister land mass directly across the Missouri River - Jameson Island. The area was purchased from willing sellers soon after the record flood of 1993. During the first week of June 1993, the Missouri River began its summer rise. By June 14th at Boonville, Missouri, the river had reached its 50-year flood elevation. About June 27th the river crested again at about 602 feet above mean sea level (msl). The 500-year flood elevation is a little over 603 feet msl and the 100-year flood elevation is a little more than 600 feet msl. A later crest came on July 30, 1993. The river crested once more, in September of 1993. The combination of these successive flood events greatly affected the Lisbon Bottoms and Jameson Island.

For about 50 days, the river was above flood stage at Boonville. According to Chart 5 in the "The Record Flood of 1993," the Missouri River displayed record flood crests at all measured locations along the Missouri River in Missouri. The "Flood Report Analysis" described many recommendations to mitigate future floods. Among those were government buyouts to impacted properties. The U.S. Fish and Wildlife Service began looking for impacted floodplain lands and The Lisbon Bottoms refuge was created. The Lisbon Bottoms are part of the Big Muddy National Fish and Wildlife Refuge.

The Lisbon Bottoms area is rich in early Missouri European-American settlement history. Cooper's Fort, founded in the early 1800s, is a nearby landmark. The area may have been settled because of the rich bottomland soils and probable abundance of Cottonwood trees that were used for building of defensive structures from marauding Indians. On January 23, 1816, Ben Cooper requested assistance from the governor in preparing for Indian wars that soon began.

The Boone's Lick historic site lies just off the floodplain to the northeast. Daniel Boone's son, Nathan, discovered the site. They boiled spring water until residual salt was left in large iron cauldrons from the condensate brackish.. The upland area has [naturally] steep loess soils that are naturally forested. Valuable hard maple, walnut, white oak and basswood line the valleys and uncultivated lands. Corn, soybeans, tobacco and large areas of grassland compose the tamed lands. Dropping off back into the Missouri River floodplain, corn and soybeans are the principle crops. Exceptions are where recent floods have deposited too much sand, or scoured low depressions forming what are now wetlands. The floodplain trees are mostly soft hardwoods such as sycamore, silver maple, and cottonwoods.

On June 21, 1993, high river waters were lapping on the county roadway and the turbulent river was suspending trees as they floated downstream. High Missouri River water levels caused adjoining contributing streams to rise. When the elevation of the river is higher than the stream beds, backwater is created, if not leveed from the floodplain, creates additional wetlands. Overflow and upward groundwater percolation saturates the bottomland soils.

According to the June, 1978, Soil Conservation Service soil survey of Howard County, some of the soils in the area are Nodaway silt loam coming off the adjoining uplands and Hodge loamy fine sand and Sarpy sand. The Sarpy sand is limited for crops and is lacking in organic matter. Sarpy sand is listed by the USDA soil surveys as being very poor for wetland plants. The Hodge sand is also generally not well suited for most types of farming. Nodaway silt loam is well suited to crops and habitat for wildlife.

Steve McIntosh collected a soil sample and Rex Bohm completed a mineral analysis. The analysis for Lisbon Bottoms was:

Eolin (wind blown) quartz silt	90%
Larger quartz silt	9 %
Dark minerals and fine organic	1 %

The very fine quartz silt appears to be a characteristic of Missouri River bottomland soils perhaps formed by wind erosion and generated by past backwater overflows and floods.

Lisbon Bottoms has been intensively farmed and not until the record flood of 1993 did use of the land revert back to its pre-settlement condition. The land is now a refuge that seemingly lies dormant. The Lisbon Bottoms' converted farmland area consists of even-aged cottonwoods, 5 to 30 feet high and common weeds one would expect to see in pastures and farmed fields such as ironwood and partridge peas. One area of mature cottonwoods was also chosen as a training site to calibrate the satellite images. The reflectance, satellite images reflecting radiation from the area being examined from above, should show a newly formed wetland signature and should be similar to other highly managed wetland sites. Sites having like reflectance probably have similar wetland characteristics.

Jameson Island, Cooper County, September 21, 2001

Jameson Island is a mirror image of Lisbon Bottoms. It lies on the opposite meander of the Missouri River and is converted cropland that is now part of the Big Muddy National Wildlife Refuge property. The refuge lies in the floodplain just below historic Arrow Rock State Park. The park was named after features recorded by the Lewis and Clark expedition. The Lewis and Clark explorers copied the namesake for the area landmarks from the river view given by native Americans. The community of Arrow Rock is now a popular historic town with a local playwright theater.

When first settled, the Missouri River was very near the town but it has since meandered away from the bluffs that bears the name of Arrow Rock. The natural features of the river's meandering are what may make Jameson Island an important wetland site in the future. During the flood of 1993, water took the shortest route downstream and flooded directly across Jameson Island. The fact that most of the island lies perpendicular to future flood flows make the property very questionable for row-crop agriculture but highly desirable for possible future natural wetland development.

Like Lisbon Bottoms, since 1993 the area has become mostly forested with even-aged cottonwoods with an understory of black willows. Levees are still present and some of the most diverse wetland habitat is on the fringes of the man-made drains that parallel the levees. Air photographs taken on September 23, 1995, show distinct erosion of the upper end of the island and corresponding large amounts of sand deposition on the middle and downstream ends of the Island.

The soil profile collected shows much the same materials as the soil from Lisbon Bottoms and consists of very fine quartz silt. Jameson Island profile does have a darker, higher organic component in the upper three inches.

Van Meter State Park, Saline County, June 29, 2001

The hills of Van Meter State Park were formerly home to native Americans. An Indian village once stood on the higher parts of the park and the Indians may have once used the Indian burial mound field and "Old Fort" area for ceremonial purposes. In 1932, the land was donated to the state for a park by the Van Meter family.

The loess-dissected hills contain some very large, fine, old growth basswood, oak and maple trees that may never have been harvested because of the steep topography and nearby marsh fields. A 40-acre natural marsh is one of the park's most extraordinary features. The Van Meter Ditch maintains the marsh's hydrology. Digital ortho quads illustrate about another 40-acre section of wetlands south and west of the park's boundary along Van Meter Ditch. Upper Ditch is controlled by the Missouri Pacific Railroad bed and drains some of the most productive soils in Missouri. The "Joy" silt loam is listed as a class I agriculture soil. Class I soil is the most productive type of soil. Most all the soils in the Grand Pass / Marshall, Missouri, area are highly productive.

The marsh area soils are both Nodaway silt loam and Aholt clay. The Nodaway is formed at the bottom of the dissected loess hills and appears to be located in the forested wetland test sites. The emergent wetland test sites' soils are the Aholt clay. Aholt clay is formed from clay settled and accumulated in areas of standing water in shallow swamps. According to the USDA soil survey, the clay is a very fine calcareous soil that is highly productive for wetland plants. The Aholt clay has a normal high water table of 0 to 1 foot below land surface.

Mineral analysis by Rex Bohm shows about 80 percent highly organic clay soil. Fifteen percent of the soil sample was fine quartz silt and about 5 percent were igneous rock fragments. Productive agricultural soil is highly impacted by row crop agriculture. The park marsh has very well documented plant diversity. Although the area is very agriculture intensive, the park is not a highly impacted area. Park personnel do create frequent managed burns to enhance species diversity. Many trees show extensive fire damage as evidence of controlled marsh succession. Without the controlled fires, the more dominant tree canopy species of silver maple and cottonwood would overrun the rarer plant species and animal and insect diversity associated with the plants. As of April 1999, Van Meter Marsh listed 110 plant species and the forested wetlands have 31 species surveyed.

At the emergent site, pecan and willow trees appear to be able to tolerate near saturated soils and numerous grapevines drape their limbs. River bulrush dominates the marsh but sweetflag, swamp smartweed, and sedges are common. The marsh fringes are ironweed, nettles and giant ragweed with silver maple and cottonwood canopy trees.

Fountain Grove Conservation Area, July 27, 2001

Fountain Grove Conservation area in Linn, Livingston and Chariton counties is part of a very large tri-county wetlands complex area. The wetland complexes are a result of three streams meeting in the tri-county area. The Grand River traverses the area from the west, Little Parsons Creek from the northwest, and Locust Creek from the northeast. All the streams have their own floodplain alluvial sediments but together, they form a broad, frequently-wetted area conducive to wetland formation. Recognizing these unique features, the U.S. Fish and Wildlife Service, Missouri Department of Conservation, and Missouri State Parks all stepped in to preserve or enhance those features valued by their mandates. Pin oaks and basswood trees are fairly common on the marsh edges.

Fountain Grove is a highly altered wetland area geared towards migrating waterfowl habitat. Water control gates, dikes and levees were built to divert water from the Little Parsons Creek and Grand River through the state wildlife area. This results in a non-natural marsh type habitat that has many benefits for water-loving red wing blackbirds and wading shorebirds, such as cattle egrets and great blue herons which are common. Turtles, frogs, and waterfowl are also common in the impounded areas.

Consequently, wetland plants are not as diverse as they would be in less hydraulically managed wildlife areas. During the July visit, the sites were flooded. River bulrush was the dominant wetland plant, with spike rush being common. The more distinctive buttonbush is also present along the dikes.

In September, 1999, three emergent sites and two forested sites were delineated. The emergent sites had dominant plants - American lotus, water smartweed, arrowhead, Pennsylvania smartweeed, and river bulrush. Forested areas were dominated by black willow and silver maple with elm and ash also present.

The soils are mostly a mixture of fine gray odorous organic silts, probably altered by frequent flooding sustained by the water control gates. In many ways, the marsh- or emergent-classed areas are more akin to shallow lake ephemeral habitat than wetlands that often are void of surface waters. The natural soils are commonly Tice and Portage and subject to severe flooding. The native soils are probably covered with the fine gray organic silt where frequent impounding occurs in the conservation area.

Pershing State Park / Swan Lake Refuge, July 27, 2001

The park is dissected by the glacial till stream named Locust Creek. Except for the immediate park area downstream to the Grand River, the Creek is highly modified and the river bottoms are intensively farmed. The stream was channelized to move water faster to have less flood impact on land adjoining the straightened stream sections. Channelized streams have several negative environmental impacts that are directly impacting some of the rare habitat features of the park. Increased stream velocities during high flows create higher sediment bed loads, which creates channel scouring and streambed degradation, or "deepening." Stream banks also have a tendency to naturally widen after being straightened. This widening by back scouring caused by logjams creates additional flow problems for downstream landowners. Felled trees create the logjams. The number of felled trees are accelerated because of increased back erosion that undercuts the trees' root masses, resulting in their tumbling into the stream. This would occur naturally, but in a straightened stream, occurs at a more rapid pace.

Increased bed loads will continue downstream in straightened areas until the stream widens and velocity slows, first allowing gravel, then sand, silt, and finally suspended clay to fall out of the water column and be deposited in the channel and shallow overflow areas. In a wetland, the hyper sedimentation causes natural wetlands to fill in at a much faster rate than normal. Sediment loads also increase in the stream because, along with channelization, agriculture lands adjoining the stream are further protected from the stream overflows by dikes or levees that are usually parallel to the stream. Since water and suspended sediment cannot move over into the floodplain and be deposited, the sediments are carried downstream until the water slows.

As Locust Creek meanders through the park, sediment is quickly deposited at the upper reaches. Logjams have also occurred at the upper and mid-reaches of the park. The lower end and western prairie edges appear less impacted by upstream channelization.

Eagle Bluffs Conservation Area, June 25, 2001

In the early 1990s the Missouri Department of Conservation purchased 4,269 acres of the McBaine Bottom's area named for the town of McBaine. The original concept was to create many wetland water treatment cells in the McBaine floodplain for final water treatment prior to discharging to the Missouri River. The City of Columbia needed to improve their quality of water treatment. The Department of Conservation entered into an agreement with the city to use treated wastewater.

The conservation area includes 13 wetland pools. The area has 450 acres of emergent marsh-like habitat and 800 acres of seasonally flooded marshes. The south border of the conservation area is the Missouri River and to the north of Perche Creek. Although access is limited to the Perche Creek area, some of the most diverse wetlands habitat can be found there. Most of the managed area is highly controlled with large water-filled dikes and water-control works. Since the area water levels are highly regulated, as at Fountain Grove Conservation to the northwest in the Grand River drainage, most the potential diversity of wetland plant species is very limited. Many if not most of the plants found in the wetland cells are actually upland plants that are periodically flooded.

Just above the McBaine Bottoms are stands of old growth hard maples jutting out from limestone bluffs. Basswood, silver maples, black walnut, and hanging grapevines line the banks of the streams as they descend into the floodplains. Swamp smartweed, hackberry and cottonwood trees outline the Providence public access on Perche Creek. The Conservation Department has several old cottonwoods that line up to appear to mark old fence rows. Smartweed and cattails dominate the impounded areas behind the dikes, and cormorants, herons, and ducks are the most noticeable wildlife. The bottoms here were once row crop fields of corn and soybeans.

Soil samples demonstrated much the same mineral analysis as found at the other Missouri River floodplain.

fine quartz silt	90%
larger igneous sand	10%
organic and clay	10%

Most of the soils here are mapped by the USDA soil maps as Sarpy very fine sandy loam and Onawa silty clay loam. Creating sustainable wetlands without constant water flow will difficult here because of the high percentage of permeable sand-like materials.

METHODS

Wetland Delineation Methodology

Field visits to each conservation area were made. We indicated what types of wetlands we were interested in and he suggested possible sites. We then reviewed maps and aerial photographs of the refuge and noted possible training sites. A reconnaissance of the area, either by foot or vehicle or both, was made. Locations from the map were determined and evaluated as to the degree of usefulness as training sites. We then located other useable areas via visual inspection.

Sites were selected based on the following criteria:

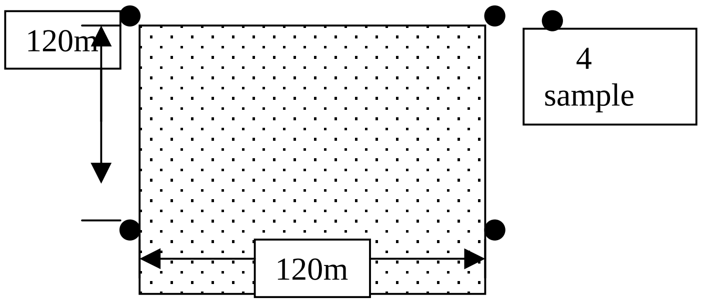
- They had to be large enough to include a 120m x 120m plot
- They had to be relatively homogeneous in terms of wetland type (shrub/scrub, emergent, etc.)
- The entire plot had to be classified as wetland, although small atypical areas within the plot were acceptable.
- Plant communities within the plot could vary, as long as the wetland type category was the same.

The area was then staked and measured for a 120m x 120m plot. Stakes were marked and flagged. To assure a “square” plot was secured, compass readings were used to obtain 90° angles at each corner.

EPA Delineation

Initially staff from the Kansas City EPA Regional Office assisted our hydrologists in delineating selected sites at Eagle Bluffs, Fountain Grove, and Pershing State Park. Water Resources Program wetland hydrologists complete the surveys at Jameson Island and Van Meter State Park.

At each of the four corners of each plot, a soil pit was dug, a vegetation survey completed, and hydrologic evaluation was made. At each of these locations, it was determined if the area was a wetland or non-wetland according to the 1987 COE delineation manual. The area within the four corners was then visually inspected and if this area contained the same hydrophytic vegetation and hydrology as the four sample plots, the entire plot was considered to be a wetland. Dominant vegetation also was noted and a determination made as to the type of wetland (shrub/scrub, emergent, riparian, and farmed wetland).



WIAP Remote Sensing Methods and Image Processing

Acquisition
Three major suppliers of satellite imagery exist that are relevant to this project: the United States Geological Survey (USGS) Earth Resources Observation Systems (EROS) Data Center (EDC), SPOT Image Corporation, and Space Imaging Corporation. All satellite imagery used in this project was acquired from these sources. Landsat 7 Enhanced Thematic Mapper (ETM+) Imagery was acquired from the USGS EDC; multi-spectral SPOT imagery was acquired from SPOT Image Corporation; and panchromatic Indian Remote Sensing Satellite (IRS) imagery and IKONOS panchromatic and multi-spectral imagery were acquired from Space Imaging Corporation.

Rectification
All satellite images were rectified using the USGS Digital Orthophoto Quadrangles (DOQ) as a base. USGS DOQ's are based on 1995 aerial photography flown under leaf off conditions and have a spatial resolution of 1m. They are the most spatially accurate, readily available, image data source available.

Satellite scene subsets were created that contained only data in and around the wetland areas of interest. This reduces the number of ground control points that need to be collected and also greatly reduces the number of DOQ's required to cover the area being rectified.

Ground control points were collected from the satellite imagery and corresponding ground control points were collected from the DOQ's. These points were used to develop the polynomial transformations used to transform the imagery to an understandable coordinate system, in this case the Universal Transverse Mercator (UTM) projection. The cubic convolution resampling algorithm was used to resample the imagery to the new coordinate system.

Preprocessing
A mask was applied to each rectified satellite scene to further refine the area of interest for additional processing. The mask consisted of a 1000M buffer around each wetland area of interest.

Classification
Masked images were classified using either a supervised or unsupervised approach. Supervised classification was applied to wetland areas where delineations had been conducted. The areas where delineations had been performed were used to generate color signatures for the classification procedure. In addition, color signatures were generated for farmed lands, bare ground and water. All color signatures were used with a maximum likelihood classification rule to determine class membership.

Unsupervised classification was applied to all wetland areas, regardless of whether delineations had been performed or not. Unsupervised classification does not require apriori information about the area being classified, as does supervised classification.
Each image was subjected to a clustering routine in ERDAS Imagine known as Isodata. Isodata generates homogeneous color signatures based on image statistics. For this project thirty signatures were specified. Using the signatures generated by the Isodata routine, a maximum likelihood classification rule was applied to determine class m.

DISCUSSION OF USES OF IMAGE PRODUCTS

Image products have been used for many years for land use description, monitoring and mapping. Acquisition costs and availability have been limiting factors in acquiring data. The current wetland inventory accomplished by the U.S. Fish and Wildlife Service was a huge task that was achieved by high altitude aerial photography. Discrimination of the wetlands was stated as limited to three acres or more. Still, on a regional scale, the NWI is very useful for all types of environmental impact evaluations and is a commendable achievement. Aerial photography, because of its ability to be near ground level, is still more appropriate for surveying and detailed local wetland change detection. However, low level photography has been prohibitory expensive.

New detailed image products can be acquired in larger scenes and still have the detail available from high altitude photography. The multi-spectral digital products have now ushered in a new era of computer-generated interpretation that will allow tasking and analysis of changes within a few weeks time, the time it takes for the satellite to fly over the same path orbiting the earth. To have digital analysis specialized software and expertise are required to train the software to recognize differences. Once trained by supervised ground verification and validation of multiple targets, very large areas can be examined very frequently at a much lower costs than previously available.

IMAGE EVALUATION MATRIX

The matrix was devised to compare the utility of several satellite data products currently available from the three vendors mentioned above. The left column contains 16 attributes of the image products. The seven products are compared on an objective scale. Attributes that increase the resolution decrease the utility of the images on regional scales and greatly increase cost.

State government can receive Landsat 7 at the cost of production, $600.00 per scene and Landsat 5 at $425.00 per scene .Other vendors are for profit and charge what the customers are willing to pay. The Landstat resolution of 15 to 30 meters and 15 meters merged is probably not detailed enough to discriminate between wetland plant assemblages but can discern larger, wetland complexes of several acres and can be imported to ARC-VIEW to develop wetlands acreage's for inventory and regional change detection.

Higher resolution or more detailed images enable visual accuracy to a much greater extent in determining land cover and vegetation differences. The IKONOS and IRS have high resolution and high acquisition costs and more data storage requirements.

All image types evaluated are suitable for visual interpretation but only the multi-spectral can be used for digital evaluations. Multi-spectral images are suitable for wetland mapping but panchromatic, similar to black and white photography is not.

General trends can be observed from the Image Evaluation Matrix. Panchromatic imagery, which is similar to black and white photography, is generally suited to visual interpretation, but not digital interpretation. On the other hand, multi-spectral imagery is suited for both visual and digital interpretation. Additionally, as the spatial resolution of the data product increases (smaller pixel size) the relative cost of that product also increases, as does the storage requirements. The spatial resolution of the Landsat and SPOT data products (15m to 30m) are not detailed enough to discriminate between wetland plant assemblages but are able to distinguish between the larger wetland complexes (more suitable for regional scale applications). The data products with smaller pixel sizes (Ikonos and IRS) are better suited to local scale analyses.

SUMMARY OF RESULTS AND FUTURE STUDIES

We believe that satellite image processing is on the cutting-edge of land-use classification and natural resources monitoring. Within a few years, increased demand should drive down acquisition costs and desire to have the information will make image attainment and interpretation commonplace among natural resource agencies. Satellite image use, while now specialized, should become as commonplace as the use of geographic information systems, the Internet, and e-mail in the 1990s.

Progress is being made toward making satellite images more accessible to the public. Landsat 7 data is currently available to the public for $600 per scene (approximately $0.05/square mile). The newer high spatial resolution images can be acquired although they are more expensive. The Water Resources Program/EPA current Wetland Urban project is using aerial photography and may compare satellite images of various wetland sites to the original NWI and current photography.

It was an original goal to produce a user-friendly “cook-book” to guide application of remote sensing technology to wetland projects. Unfortunately, cutting-edge technology requires specialized experts and software, and does not lend itself to simplified guides. As the use of satellite based imagery increases, simplified software routines may be capable of interpreting satellite data from raw image data to wetland evaluations.

Processed data from this project are stored on CD-ROM and are available for reproduction and administrative processing costs from the Missouri Department of Natural Resources, Geological Survey and Resource Assessment Division in Rolla, Missouri.

WIAP[1] satellite image matrix	IKONOS Panchromatic	IKONOS Multispectral	IRS[2] Panchromatic	L7[3] Panchromatic	L7[3] Multispectral	L7[3] Pan/Multi Merge	SPOT Multispectral
Cost ($)	high	high	moderate	low	low	low	moderate
Data source (see contact info below)	Space Imaging Corporation	Space Imaging Corporation	Space Imaging Corporation	USGS Eros Data Center	USGS Eros Data Center	USGS Eros Data Center	SPOT Image Corporation
Spatial Resolution (m)	1	4	5	15	30	15	20
Spectral Resolution	visible	visible, near infrared	visible	visible	visible, near & middle infrared	visible, near & middle infrared	visible, near & middle infrared
# of data channels	1	4	1	1	6	6	3 or 4
Radiometric Resolution	8 or 11 bit quantization	8 or 11 bit quantization	8 bit quantization	8 bit quantization	8 bit quantization	8 bit quantization	8 bit quantization
Temporal Resolution (days)	acquired as tasked	acquired as tasked	48-50	16	16	16	acquired as tasked
Footprint (km)	minimum of 5	minimum of 5	70	185	185	185	60
Defined as cloud free	< 20%	< 20%	NA	listed in 10% increments	listed in 10% increments	listed in 10% increments	NA
Delivery time	variable	variable	approximately 2 weeks	generally < 1 week	generally < 1 week	generally < 1 week	variable
Data format	GEOTiff[4]	GEOTiff[4]	BSQ[5]	GEOTiff[4]	GEOTiff[4]	GEOTiff[4]	BIL[6]
Data storage requirements	high	high	high	moderate	low	high	low
Appropriate project scale	local	local	local	regional	regional	regional	regional
Appropriate for visual interpretation	yes	yes	yes	yes	yes	yes	yes
Appropriate for computer interpretation	no	yes	no	no	yes	yes	yes
Appropriate for wetland mapping	limited	yes	limited	limited	yes	yes	yes

Footnotes	Contact Information		
[1] Wetlands Image Analysis Project	Space Imaging Corporation	USGS Eros Data Center	SPOT Image Corporation
[2] Indian Remote Sensing Satellite	12076 Grant Avenue	47914 252nd Street	1897 Preston White Drive
[3] Landsat 7	Thorton, CO 80241	Sioux Falls, SD 57198-0001	Reston, Virginia 20191
[4] Georeferenced raster tiff image	Phone US: 1-800-425-2997	Phone US: 1-800-252-4547	Phone: 1-800-ASK-SPOT
[5] Band Sequential	Fax: 1-303-254-2215	Fax: 1-605-594-6589	FAX: 1-703-648-1813
[6] Band Interleaved by Line	Email: info@spaceimaging.com	Email: custserv@usgs.gov	Email: info@spot.com